II. *Experimental Researches in Electricity.—Twenty-second Series (continued).*

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§ 28. *On the crystalline polarity of bismuth and other bodies, and on its relation to the magnetic and electric form of force (continued).*

¶ iv. *Crystalline condition of various bodies.* ¶ v. *Nature of the magnecrystallic force, and general observations.*

¶ iv. *Crystalline condition of various bodies.*

2535. *ZINC.*—Plates of zinc broken out of crystallized masses gave irregular indications, and, being magnetic from the impurity in them, the effects might be due entirely to that circumstance. Pure zinc was thrown down electro-chemically on platina from solutions of the chloride and the sulphate. The former occurred in ramifying dendritic associations of small crystal; the latter in a compact close form. Both were free from magnetic action and freely diamagnetic, but neither showed any trace of the magnecrystallic action.

2536. *Titanium**.—Some good crystals of titanium obtained from the bottom of an iron furnace, were cleansed by the alternate action of acids and fluxes until as clear from iron as I could procure them. They were bright, well-formed and magnetic (2371), and contained iron, I think, diffused through their whole mass, for nitro-muriatic acid, by long boiling, continually removed titanium and iron from them. These crystals had a certain magnetic property which I am inclined to refer to their crystalline condition. When between the poles of the electro-magnet, they set; and when the electric current was discontinued, they still set between the poles of the enfeebled magnet as they did before. If left to itself a crystal always took the *same* position, showing that it was constantly rendered magnetic in the same direction. But if a crystal was placed and kept in another position between the magnetic poles whilst the electric current was on, and afterwards the current suspended, and then the crystal set free, it pointed between the poles of the enfeebled magnet in this new direction; showing that the magnetism was in a different direction in the body

* For these and many other crystals I am indebted to the kindness of Sir HENRY T. DE LA BECHE and Mr. TENNANT.

of the crystal to that which it had before. If now the magnet were reinvigorated by the electric current, the crystal instantly spun round and took a magnetic state in the first or original direction. The crystals could in fact become magnetized in any direction, but there was one direction in which they could be magnetized with a facility and force greater than in any other. From the appearances I am inclined to refer this to the crystalline condition, but it may be due to an irregular diffusion of iron in the masses of titanium. The crystals were too small for me to make out the point clearly.

2537. *Copper.*—I selected some good crystals of native copper, and, having carefully separated them from the mass, examined them in respect of their magnecrystallic force. At the horse-shoe magnet (2486.) they gave no signs of such power, whatever the direction in which they were suspended, but stood in any position; and any degree of torsion, however small, applied at the upper extremity of the suspending filament was obeyed at once, and to the full extent, by the crystal beneath. When subjected to the electro-magnet, the phenomena of arrest and revulsion were produced (2513. 2310.), as was to be expected. If after the arrest the magnetic force were continued, there was no slow advance of the crystal up to a distinct pointing position (2512.); it stood perfectly still in any position. So there is no evidence of magnecrystallic action in this case.

2538. *Tin.*—I selected from block and grain tin some pieces which appeared, by their external forms and the surface produced under the action of acids, to have a regular crystalline structure internally; and, cutting off portions, carefully submitted them to the power of the magnets, but there was no appearance of any magnecrystallic phenomena. Indications of the arresting and revulsive actions were presented, and also of diamagnetic force, but nothing else. I also examined some crystals of tin obtained by electro-chemical deposition. They were pure and diamagnetic: they were arrested and revulsed, but they showed no signs of magnecrystallic action.

2539. *Lead.*—Lead was crystallized by fusion, partial solidification, and pouring off (2457.), and some very fair crystals, having the general form of octohedra, obtained. Observed at the magnets, these were arrested and revulsed feebly, but presented no magnecrystallic phenomena. Some fine crystalline plates of lead obtained electro-chemically from the decomposition of the acetate by zinc, were submitted to the magnet: they were pure, diamagnetic, and were arrested and revulsed, but presented no appearance of magnecrystallic action.

2540. *Gold.*—Three fine large crystals of gold were examined. They were diamagnetic, and easily arrested (2310. 2340.); the revulsion did not take place, because of their octohedral or orbicular form. They presented no magnecrystallic indications.

2541. *Tellurium.*—Two fractured pieces of this substance, presenting large and parallel planes of cleavage, were examined: both pointed, and the greatest length was across the axial line between flat-faced poles (2463.). I think the effects were

in part, if not altogether, due to the magnecrystallic state of the substance; but I do not think the evidence was quite conclusive.

2542. *Iridium and Osmium alloy.*—The native grains of iridium and osmium are often flat, presenting two planes looking like crystal planes, which are parallel to each other even when the grains are thick. Some of the largest and most crystalline were selected, and, after ignition with flux and digestion in nitromuriatic acid, were examined at the magnet. Some were more magnetic than others, being attracted; others were very little magnetic: the latter were selected and examined more carefully. These all pointed with great readiness and force, comparatively speaking; for they were not above one-fifteenth of an inch long, and yet they set freely when the magnetic poles were three or four inches apart. The faces of the crystalline particles were *always* towards the poles, and their length consequently not *in* but *across* the axial line; and this was true whether the distance between the poles was small or great, or whether flat-faced or conical poles were used. I believe they were magnecrystallic.

2543. *Fusible metal.*—Crystals of fusible metal (2457.) pointed, but the crystals, which were apparently quadrangular plates or prisms, were not good, and the evidence not clear and distinct.

2544. *Wires.*—I thought it possible that thin wires, which by the action of acids exhibited fibrous arrangements, might have their particles in a state approaching to the crystalline condition, and therefore submitted bundles of platinum, copper, and tin wire to the action of the magnet; but no indications of magnecrystallic action appeared.

2545. I submitted several metallic compounds to the power of the magnet, applied so as to develope any indication of the magnecrystallic phenomena. Galena, native cinnabar, oxide of tin, sulphuret of tin, native red oxide of copper, Brookite or oxide of titanium, iron pyrites, and also diamond, fluor spar, rock-salt and boracite, being all well-crystallized and diamagnetic, presented no evidence of the magnecrystallic force. Native and well-crystallized sulphuret of copper, sulphuret of zinc, cobalt glance and leucites were magnetic. Arsenical iron, specular iron and magnetic oxide of iron were still more so. I could not in any of them distinguish any magnetic results due to crystallization.

2546. On examining magnetic salts, several of them presented very striking magnecrystallic phenomena. Thus, with *sulphate of iron*, the first crystal which I employed was suspended with the magnecrystallic axis vertical, and it presented no particular appearances; only the longest horizontal direction went into the magnetic axis pointing feebly. But on turning the piece 90° (2470.), instantly it pointed with much force, and the greatest length went equatorially. The crystal was compounded of superposed flat crystals or plates, and the magnecrystallic axis went directly across these; it was easy therefore, after one or two experiments, to tell beforehand how the crystal should be suspended, and how it would point. Whether the crystals were

long, or oblique, or irregular, still the magnecrystallic force predominated and determined the position of the crystal, and this happened whether pointed or flat poles were used, and whether they were near together or far asunder. The magnecrystallic axis is perpendicular, or nearly so, to two of the sides of the rhomboidal prism. I have some small prismatic crystals of which the length is nearly three times the width of the prism; but when both the length and the magnecrystallic axis are horizontal, no power of the magnet, or shape, or position of the poles, will cause the length to take the axial direction, for that is constantly retained by the magnecrystallic axis, so greatly does it predominate in power over the mere magnetic force of the crystal. Yet this latter is so great as at times to pull the suspending fibre asunder when the crystal is above the poles (2615.).

2547. *Sulphate of nickel.*—When a crystal of sulphate of nickel was suspended in the magnetic field, its length set axially. This might be due, either to mere magnetic force, or partly to magnecrystallic force. Therefore I cut a cube out of the crystal, two faces of which were perpendicular to the length of the original prism. This cube pointed well in the magnetic field, and the line coincident with the axis of the prism was that which pointed axially, and represented the magnecrystallic axis. Even when the cube was reduced in this direction and converted into a square plate whose thickness coincided with the magnecrystallic axis, it pointed as well as before, though the shortest dimensions of the piece was now axial.

2548. The *persulphate of ammonia and iron*, and the *sulphate of manganese*, did not give any indication of magnecrystallic phenomena; the *sulphate of ammonia and manganese* I think did, but the crystals were not good. The sulphate of potassa and nickel is magnecrystallic. All three salts were magnetic.

2549. Thus it seems that other bodies besides bismuth, antimony and arsenic, present magnecrystallic effects. Amongst these are the alloy of iridium and osmium, probably tellurium and titanium, and certainly the sulphates of iron and nickel. Before leaving this part of the subject, I may remark that this property has probably led me into error at times on a former occasion (2290.). A mistake with arsenic (2383.) might very easily arise from this cause.

¶ v. *On the nature of the magnecrystallic force, and general observations.*

2550. The magnecrystallic force appears to be very clearly distinguished from either the magnetic or diamagnetic forces, in that it causes neither approach nor recession; consisting not in attraction or repulsion, but in its giving a certain determinate position to the mass under its influence, so that a given line in relation to the mass is brought by it into a given relation with the direction of the external magnetic power.

2551. I thought it right very carefully to examine and prove the conclusion, that there was no connection of the force with either attractive or repulsive influences. For this purpose I constructed a torsion-balance, with a bifilar suspension of cocoon

silk, consisting of two bundles of seven filaments each, four inches long and one-twelfth of an inch apart; and suspended a crystal of bismuth (2457.) from one end of the lever, so that it might be fixed and retained in any position. This balance was protected by a glass case, outside of which the conical terminal of one pole of the great electro-magnet (2247.) was adjusted, so as to be horizontal, at right angles to the lever of the torsion-balance, and in such a position that the bismuth crystal was in the prolongation of the axis of the pole, and about half an inch from its extremity when all was at rest. The other pole, four inches off, was left large so that the lines of magnetic force should diverge, as it were, and rapidly diminish in strength from the end of the conical pole. The object was to observe the degree of repulsion exerted by the magnet on the bismuth, as a diamagnetic body, either by the distance to which it was repelled, or by the torsion required to bring it back to its first position; and to do this with the bismuth, having its magnecrystallic axis at one time axial or parallel to the lines of magnetic force, at another equatorial, observing whether any difference was produced.

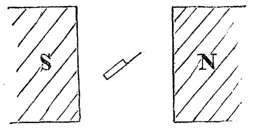
2552. The crystal was therefore placed with its magnecrystallic axis first parallel to the lines of magnetic force, and then turned four times in succession 90° in a horizontal plane, so as to observe it under all positions of the magnecrystallic axis; but in no case could any difference in the amount of the repulsion be observed. In other experiments the axis was placed oblique, but still with the same result. If there be therefore any difference it must be exceedingly small.

2553. A corresponding experiment was made, hanging the crystal as a pendulum by a bifilar suspension of cocoon silk thirty feet in length, with the same result.

2554. Another very striking series of proofs that the effect is not due to attraction or repulsion, was obtained in the following manner. A skein of fifteen filaments of cocoon silk, about fourteen inches long, was made fast above, and then a weight of an ounce or more hung to the lower end; the middle of this skein was about the middle of the magnetic field of the electro-magnet, and the square weight below rested against the side of a block of wood, so as to give a steady, silken, vertical axis, without swing or revolution. A small strip of card, about half an inch long, and the tenth of an inch broad, was fastened across the middle of this axis by cement; and then a small prismatic crystal of sulphate of iron about 0·3 of an inch long, and 0·1 in thickness, was attached to the card, so that the length, and also the magnecrystallic axis, were in the horizontal plane; all the length was on one side of the silken axis, so that as the crystal swung round, the length was radius to the circle described, and the magnecrystallic axis parallel to the tangent.

2555. This crystal took a position of rest due to the torsion force of the suspending skein of silk; and the position could be made any one that was desired, by turning the weight below. The torsion force was such, that, when the crystal was made to vibrate on its silken axis, forty complete (or to and fro) vibrations were performed in a minute.

Fig. 4.



2556. When the crystal was made to stand between the flat-faced poles (2463.) obliquely, as in fig. 4, the moment the magnet was excited it moved, tending to stand with its length equatorial or its magnecrystallic axis parallel to the lines of magnetic force. When the N pole was removed, and the experiment repeated, the same effect took place, but not as strongly as before; and when, finally, the pole S was brought as near to the crystal as it could be, without touching it, the same result occurred, and with more strength than in the last case.

2557. In the two latter experiments, therefore, the crystal of sulphate of iron, though a magnetic body and strongly attracted by such a magnet as that used, actually *receded* from the pole of the magnet under the influence of the magnecrystallic condition.

2558. If the pole S be removed and that marked N be retained for action on the crystal, then the latter approaches the pole, urged by both the magnetic and magnecrystallic forces; but if the crystal be revolved 90° to the left, or 180° to the right, round the silken axis, so as to come into the contrary or opposite position, then this pole repels or rather causes the removal to a distance of the crystal, just as the former did. The experiment requires care, and I find that conical poles are not good; but with attention I could obtain the results with the utmost readiness.

2559. The sulphate of iron was then replaced by a crystalline plate (2480.) of bismuth, placed as before on one side of the silk suspender, and with its magnecrystallic axis horizontal. Making the position the same as that which the crystal had in relation to the N pole in the former experiment (2556.), so that to place its axis parallel to the lines of magnetic force it must approach this magnetic pole, and then throwing the magnet into an active state, the bismuth moved accordingly, and did approach the pole, against its diamagnetic tendency, but under the influence of the magnecrystallic force. The effect was small but distinct.

2560. Anticipating, for a short time, the result of the reasoning to be given further on (2607.), I will describe a corresponding effect obtained with the red ferro-prussiate of potassa. A crystal of this salt had its acute linear angles ground away, so as to convert it into a plate with faces parallel to the plane of the optic axis, and was then made to replace the plate of bismuth. Being in the position before represented (2556.), and the magnet rendered active, it moved, placing the plane of the optic axes equatorially, as Plücker describes. When the pole N was removed and S brought up to the crystal, the same motion occurred, the crystal *retreating from* the pole; and when S pole was removed and N brought towards the crystal, it moved as before, the whole body now *approaching* towards the pole. On inclining the crystal the other way, i. e. making its place on the other side of the equatorial line, the S pole caused it to *approach* and the N pole to *recede*. So that the same pole seemed able either to attract or repel the same side of the crystal; and either pole could be made to show this apparent attractive and repulsive force.

2561. Hence a proof that neither attraction nor repulsion causes the set, or

governs the final position of the body, or of any of the bodies whose movements are due to the same cause (2607.).

2562. This force then is distinct in its character and effects from the magnetic and diamagnetic forms of force. On the other hand, it has a most manifest relation to the crystalline structure of the bismuth and other bodies; and therefore to the molecules, and to the power by which these molecules are able to build up the crystalline masses. It appears to me impossible to conceive of the results in any other way than by a mutual reaction of the magnetic force, and the force of the particles of the crystal on each other: and this leads the mind to another conclusion, namely, that as far as they can act on each other they partake of a like nature; and brings, I think, fresh help for the solution of that great problem in the philosophy of molecular forces, which assumes that they all have one common origin (2146.).

2563. Whether we consider a crystal or a particle of bismuth, its polarity has a very extraordinary character, as compared with the polarity of a particle in the ordinary magnetic state, or when compared with any other of the dual conditions of physical force; for the opposite poles have *like* characters; as is shown first of all by the diametral pointing of the masses (2461.), and also by the physical characters and relations of crystals generally. As the molecules lie in the mass of a crystal, therefore, they can in no way represent, or be represented by, the condition of a parcel of iron filings between the poles of a magnet, or the particles of iron in the keeper when in its place; for these have poles of *different* names and quality adhering together, and so giving a sort of structure; whereas, in the crystal, the molecules have poles of like nature towards each other, for, so to say, all the poles are alike.

2564. As made manifest by the phenomena, the magnecrystallic force is a force acting at a distance; for the crystal is moved by the magnet at a distance (2556. 2574.), and the crystal also can move the magnet at a distance. To produce the latter result, I converted a steel bodkin, about three inches long, into a magnet; and then suspended it perpendicularly by a single cocoon filament four inches long, from a small horizontal rod, which again was suspended by its centre and another length of cocoon filament, from a fixed point of support. In this manner the bodkin was free to move on its own axis, and could also describe a circle about $1\frac{1}{2}$ inch in diameter; and the latter motion was not hindered by any tendency of the needle to point under the earth's influence, because it could take any position in the circle and yet remain parallel to itself.

2565. A support perfectly free from magnetic action was constructed of glass rod and copper wire, which passing through the bottom of the stand, and being in the prolongation of the upper axis of motion, was concentric with the circle which the little magnet could describe; its height was such that it could sustain a crystal or any other substance level with the pole at the lower end of the needle, and in the centre of the small circle in which the latter could revolve around it. By moving the lower end of the support, the upper end also could be made to approach to or

recede from the magnet. The whole was covered with a glass shade, and when left to become of uniform temperature, and at rest, the needle magnet was found to take up a *constant* position under the torsion force of the suspending filaments. Further, any rotation of the glass and copper wire support did not produce a final change in the position of the magnet; for though the motion of the air would carry the magnet away, it returned, ultimately, to the same spot. When removed from this spot, the torsion force of the silk suspension made the system oscillate; the time of a half oscillation, or a passage in one direction, was about three minutes, and of a whole oscillation therefore six minutes.

2566. When a crystal bismuth was fixed on the support with the magnecrystallic axis in a horizontal direction, it could be placed near the lower pole of the magnet in any position, and being then left for two or three hours, or until by repeated examination the magnetic pole was found to be stationary, the place of the latter could be examined and the degree and direction in which it was affected by the bismuth ascertained. Extreme precaution was required in these observations, and all steel or iron things, as spectacles, knives, keys, &c., had to be dismissed from the observer before he entered the place of experiment; and glass candlesticks were used. The effect produced was but small, but the result was, that if the direction of the magnecrystallic axis made an angle of 10°, 20°, or 30° with the line from the magnetic pole to the middle of the bismuth crystal, then the pole followed it, tending to bring the two lines into parallelism; and this it did whichever end of the magnecrystallic axis was towards the pole, or whichever side it was inclined to. By moving the bismuth at successive times, the deviation of the magnetic pole could be carried up to 60°.

2567. The crystal of bismuth therefore is able to react upon and affect the magnet at a distance.

2568. But though it thus take up the character of a force acting at a distance, still it is due to that power of the particles which makes them cohere in regular order, and gives the mass its crystalline aggregation; which we call at other times the attraction of aggregation, and so often speak of as acting at *insensible* distances.

2569. For the further explication of the nature of this force, I proceeded to examine the effect of heat on crystals of bismuth when in the magnetic field. The crystals were suspended either by platina or fine copper wire, and heated, sometimes by a small spirit-lamp flame applied directly, sometimes in an oil-bath placed between the magnetic poles; and though the upward currents of air and fluid were strong in these cases, they were far too weak to overcome the set caused by magnecrystallic action, and helped rather to show when that action was weakened or ceased.

2570. When the temperature was gradually raised in the air the bismuth crystal continued to point, until of a sudden it became indifferent in that respect, and turned in any direction under the influence of the rising currents of air. Instantly removing the lamp flame the bismuth revolved slowly and regularly, as if there were no tendency to take up one position more than another, or no remains of magnecrystallic

action; but in a few seconds, as the temperature fell, it resumed its power of pointing; and, apparently, in an instant and with full force, and the pointing was precisely in the same direction as at first. On examining the crystal carefully, its external shape and its cleavage showed that, as a crystal, it was unchanged; but the appearance of a minute globule of bismuth, which had exuded upon the surface in one place, showed that the temperature had been close upon the point of fusion.

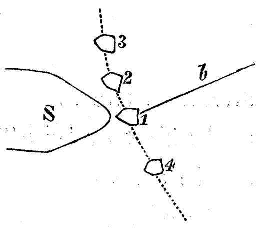
2571. The same result occurred in the oil-bath, except that as removing the lamp from the oil-bath did not immediately stop the addition of heat to the bismuth, so more of the latter was melted; and about one-fourth of the metal appeared as a drop hanging at the lower part. Still the whole mass lost its power at the high temperature, and the power was regained in the same direction, but in a less degree on cooling. The diminished force was accounted for on breaking up the crystal; for the parts which had been liquefied were now crystallized irregularly, and therefore, though active at the beginning of the experiment, were neutral at the end.

2572. As heat has this effect, the expectation entertained (2502.) of crystallizing bismuth regularly *in the magnetic field* is of course unfounded; for the metal must acquire the solid state, and be lowered through several degrees probably, before it can exhibit the magnecrystallic phenomena. If heat has the same effect on all bodies prior to their liquefaction, then, of course, such a process can be applied to none of them.

2573. A crystallized piece of antimony was subjected to the same experiment, and it also lost its magnecrystallic power below a dull red heat, and just as it was softening so as to take the impression of the copper loop in which it was hung. On being cooled it did not resume its former state, but then became ordinarily magnetic and pointed. This I conclude arose from iron affected by the flame and heat of the spirit-lamp; for, as the heat was high enough to burn off part of the antimony and make it rise in fumes of oxide of antimony, so this might set a certain portion of iron free which the carbon and hydrogen of the flame would leave in a very magnetic state (2608.).

2574. In further elucidation of the mutual action of the bismuth and the magnet, the bismuth was suspended, as already described (2551.), on the bifilar balance, but so turned that its magnecrystallic axis, being horizontal, was not parallel or perpendicular to the arm of the lever, but a little inclined, as in the figure (5.), where 1 represents the crystal of bismuth attached to the balance arm *b*, the axis of which is so placed that the crystal can swing through the various positions 1, 2, 3, 4.; S is the pole of the magnet separated only by the glass of the shade. It is manifest that in position 1 the magnecrystallic axes and the lines of magnetic force are parallel to each other; whereas in the positions 2, 3, 4, they are oblique. When the apparatus was so arranged that the crystal of bismuth rested at 1, the superinduction of the full magnetic force sent it towards 4; a result of diamagnetic action. When however the

Fig. 5.



bismuth had its place of rest at 2, the development of the magnetic force did not make it pass towards 3, in accordance with the former result, but towards 1, which it usually attained and often passed, going a little towards 4. In this case the magnecrystallic and the diamagnetic forces were opposed to each other, and the former gained the advantage up to position 1.

2575. But though the crystal of bismuth in these cases moves across the lines of force in the magnetic field, it cannot be expected to do so in a field where the lines are parallel and of equal force, as between flat-faced poles; the crystal being restrained so as to move only parallel to itself; for under such circumstances the forces are equal in both directions and on both sides of the mass, and the only tendency the crystal has, in relation to its magnecrystallic condition, is to turn round a vertical axis until it is in its natural position in the magnetic field.

2576. A most important question next arises in relation to the magnecrystallic force, namely, whether it is an original force inherent in the crystal of bismuth, &c., or whether it is induced under the magnetic and electric influences. When a piece of soft iron is held in the vicinity of a magnet it acquires new powers and properties; some persons assume this to depend upon the development by induction of a new force in the iron and its particles, like in nature to that in the inducing magnet: by others it is considered that the force originally existed in the particles of the iron, and that the inductive action consisted only in the arrangement of all the elementary forces in one general direction. Applying this to the crystal of bismuth, we cannot make use of the latter supposition in the same manner; for all the particles are arranged beforehand, and it is that very arrangement of them and their forces which gives the bismuth its power. If the particles of a substance be in the heterogeneous condition possessed by those of the iron in its unmagnetic state, then the magnetic force may develope the magnetic, and also the diamagnetic condition, which probably is a condition of induction; but it does not appear at once, that it can develope a state of the kind now under consideration.

2577. That the particles hold their own to a great extent in all the results is manifest, by the consideration that they have an inherent power or force, the crystalline force, which is so unchangeable that no treatment to which they can be subjected can alter it; that it is this very force which, placing the particles in a regular position in the mass, enables them to act jointly on the magnet or the electric current, and affect or be affected by them; and that if the particles are not so arranged, but are in all directions in the mass, then the sum of their forces externally is nothing, and no inductive exertion of the magnet or current can develope the slightest trace of the phenomena.

2578. And that particles even before crystallization can act in some degree at a distance, by virtue of their crystallizing force, is, I think, shown by the following

fact. A jar containing about a quart of solution of sulphate of soda, of such strength as to crystallize when cold by the touch of a crystal of the salt or an extraneous body, was left, accidentally, for a week or more unattended to and undisturbed. The solution remained fluid; but on the jar being touched, crystallization took place throughout the whole mass at once, producing clear, distinct, transparent plates, which were an inch or more in length, up to half an inch in breadth; and very thin, perhaps about the one-fiftieth or one-sixtieth of an inch. These were all horizontal, and of course parallel to each other; and I think, if I remember rightly, had their length in the same direction; and they were alike in character, and, apparently, in quantity in every part of the jar. They almost held the fluid in its place when the jar was tilted; and when the liquid was poured off presented a beautiful and uniform assemblage of crystals. The result persuaded me, at the time, that, though the influence of a particle in solution and about to crystallize, must be immediately and essentially upon its neighbours, yet that it could exert an influence beyond these, without which influence, the whole mass of solution could hardly have been brought into such a uniform crystallizing state. Whether the horizontality of the plates can have any relation to the almost vertical lines of magnetic force, which from the earth's magnetism was pervading the solution during the whole time of its rest, is more than I will venture to say.

2579. The following are considerations which bear upon this great question (2576.) of an original or an induced state.

2580. In the first place, the bismuth carries off no power or particular state from the magnetic field, able to make it affect a magnet (2504.); so that if the condition acquired by the crystal be an induced condition, it is probably a transient one, and continues only whilst under induction. The fact therefore, though negative in its evidence, agrees, as far as it tells, with that supposition.

2581. In the next place, if the effect were wholly due, as far as the crystal is concerned, to an original power inherent in the mass, we might expect to find the earth's magnetism, or any weak magnet, affecting the crystal. It is true that a weak magnetic force ought to *induce* any given condition in a crystal of bismuth just as well as a stronger, only proportionally. But if the given condition were inherent in the crystal, and did not change in its amount by the degree of magnetic force to which it was subjected, then a weak magnetic force ought to act more decidedly on the bismuth than it would do if the condition were induced in the bismuth, and only in proportion to its own force. Whatever the value of the argument, I was induced to repeat the experiment of the earth's influence (2505.) very carefully, and by sheltering the suspended crystals in small flasks or jar contained within the larger covering jar, and making the experiment in an underground place of uniform and constant temperature, I was able to exclude every effect of currents of air, so that the crystals obeyed the slightest degree of torsion given to the suspending fibre by the index above. Under these circumstances I could obtain no indications of pointing by

the earth's action, either with crystals of bismuth or of sulphate of iron. Perhaps at the equator, where the lines of force are horizontal, they might be rendered sensible.

2582. In the third place, assuming that there is an original force in the crystals and their molecules, it might be expected that they would show some direct influence upon each other, independent of the magnetic force, and if so the best possible argument would be thus obtained that the force which is rendered manifest in the magnetic field was inherent in them. But on placing a large crystal with its magnecrystallic axis horizontal under a smaller and suspended one, or side by side with it, I could procure no signs of mutual action; even when the approximated parts of the crystals were ground or dissolved away, so as to let the two masses come as near as possible to each other, having large surfaces at the smallest possible distance. Extreme care is required in such experiments (2581.), or else many results are produced which seem to show a mutual affection of the bodies.

2583. Neither could I find any trace of mutual action between crystals of bismuth, or of sulphate of iron, when they were both in the *magnetic field*, the one being freely suspended and the other brought in various positions near to it.

2584. From the absence therefore or extreme weakness of any power in the crystals to affect each other, and also from the action of heat which can take away the power of the crystal before it has lost its mere crystalline condition (2570.), I am induced to believe that the force manifested in the crystal when in the magnetic field, which appears by external actions, and causes the motion of the mass, is chiefly and almost entirely *induced*, in a manner, subject indeed to the crystalline force, and finally additive to it; but at the same time exalting the force and the effects to a degree which they could not have approached without the induction.

2585. In that case the word magnetocrystallic ought probably to be applied to this force, as it is generated or developed under the influence of the magnet. The word magnecrystallic I used purposely to indicate that which I believed belonged to the crystal itself, and I shall still speak of the magnecrystallic axis, &c. in that sense.

2586. This force appears to me to be very strange and striking in its character. It is not polar, for there is no attraction or repulsion. Then what is the nature of the mechanical force which turns the crystal round (2460.), or makes it affect a magnet (2564.)? It is not like a turning helix of wire acted on by the lines of magnetic force; for there, there is a current of electricity required, and the ring has polarity all the time and is powerfully attracted or repelled*.

2587. If we suppose for a moment that the axial position is that in which the crystal is unaffected, and that it is in the oblique position that the magnecrystallic axial direction is affected and rendered polar, giving two tensions pulling the crystal round, then there ought to be attractions at these times, and an obliquely

* Perhaps these points may find their explication hereafter in the action of contiguous particles (1663. 1710. 1729. 1735. 2443.).

presented crystal ought to be attracted by a single pole, or the nearest of two poles; but no action of this kind appears.

2588. Or we might suppose that the crystal is a little more apt for magnetic induction, or a little less apt for diamagnetic induction, in the direction of the magnecrystallic axis than in other directions. But, if so, it should surely show polar attractions in the case of the magnetic bodies, as sulphate of iron (2557. 2583.); and in the case of diamagnetic bodies, as bismuth, a difference in the degree of repulsion when presented with the magnecrystallic axis parallel and perpendicular to the lines of magnetic force (2552.); which it does not do.

2589. I do not remember heretofore such a case of force as the present one, where a body is brought into position only, without attraction or repulsion.

2590. If the power be induced, it must be like, generally, to its inducing predominants; and these are, at present, the magnetic and electric forces. If induced, subject to the crystalline force (2577.), it must show an intimate relation between it and them. How hopeful we may be, therefore, that the results will help to throw open the doors which may lead us to a full knowledge of these powers (2146.), and the combined manner in which they dwell in the particles of matter, and exert their influence in producing the wonderful phenomena which they present.

2591. I cannot resist throwing forth another view of these phenomena which may possibly be the true one. The lines of magnetic force may perhaps be assumed as in some degree resembling the rays of light, heat, &c.; and may find difficulty in passing through bodies and so be affected by them, as light is affected. They may, for instance, when a crystalline body is interposed, pass more freely, or with less disturbance, through it in the direction of the magnecrystallic axis than in other directions. In that case, the position which the crystal takes in the magnetic field with its magnecrystallic axis parallel to the lines of magnetic force, may be the position of no, or of least resistance; and therefore the position of rest and stable equilibrium. All the diametral effects would agree with this view. Then, just as the optic axis is to a ray of polarized light, namely, the direction in which it is not affected, so would the magnecrystallic axis be to the lines of magnetic force. If such were the case, then, also, as the phenomena are developed in crystalline bodies, we might hope for the discovery of a series of effects dependent upon retardation and influence in direction, parallel to the beautiful phenomena presented by light with similar bodies. In making this supposition, I do not forget the points of inertia and momentum; but such an idea as I can form of inertia does not exclude the above view as altogether irrational. I remember too, that, when a magnetic pole and a wire carrying an electric current are fastened together, so that one cannot turn without the other, if the one be made axis the other will revolve round and carry the first with it; and also, that if a magnet be floated in mercury and a current sent down it, the magnet will revolve by the powers which are *within* its mass. With my imperfect mathematical knowledge, there seems as much difficulty in these motions as in the

one I am supposing, and therefore I venture to put forth the idea*. The hope of a polarized bundle of magnetic forces is enough of itself to make one work earnestly with such an object, though only in imagination, before us; and I may well say that no man, if he take industry, impartiality and caution with him in his investigations of science, ever works experimentally in vain.

2592. I have already referred, in the former paper (2469.), to PLÜCKER's beautiful discovery and results in reference to the repulsion of the optic axis† of certain crystals by the magnet, and have distinguished them from my own obtained with bismuth, antimony and arsenic, which are not cases of either repulsion or attraction; believing then, with PLÜCKER, that the force there manifested is an optic axis force, exerted in the equatorial direction; and therefore existing in a direction at right angles to that which produces the magnecrystallic phenomena.

2593. But the relations of *both* to crystalline structure, and therefore to the force which confers that condition, are most evident. Other considerations as to position, set, and turning, also show that the two forces, so to say, have a very different relation to each other to that which exists between them and the magnetic or diamagnetic force. As, therefore, this strong likeness on the one hand, and distinct separation on the other is clearly indicated, I will endeavour to compare the two sets of effects, with the view of ascertaining whether the force exerted in producing them is not identical.

2594. I had the advantage of verifying PLÜCKER's results under his own personal tuition in respect of tourmaline, staurolite, red ferro-prussiate of potassa, and Iceland spar. Since then, and in reference to the present inquiry, I have carefully examined calcareous spar, as being that one of the bodies which was at the same time free from magnetic action, and so simple in its crystalline relations as to possess but one optic axis.

2595. When a small rhomboid, about 0·3 of an inch in its greatest dimension, is suspended, with its optic axis horizontal, between the pointed poles (2458.) of the electro-magnet, approximated as closely as they can be, to allow free motion, the rhomboid sets in the equatorial direction, and the optic axis coincides with the magnetic axis; but, if the poles be separated to the distance of half, or three-quarters of an inch, the rhomboid turned through 90°, and set with the optic axis in the equatorial direction, and the greatest length axial. In the first instance the diamagnetic force overcame the optic axis force; in the second the optic axis force was the stronger of the two.

2596. To remove the diamagnetic effect I used flat poles (2463.), and then the little rhomboid always set in, or vibrated about, that position in which its optic axis was equatorial.

* See note (2639.) at the end.

† On the Repulsion of the Optic Axes of Crystals by the Poles of a Magnet, POGGENDORFF's Annalen, vol. lxxii., October 1847, or TAYLOR's Scientific Memoirs, vol. v. p. 353.

2597. I also took three cubes of calcareous spar (1695.), in which the optic axes were perpendicular to two of the faces, of the respective dimensions of 0·3, 0·5, and 0·8 of an inch in the side, and placed these in succession in the magnetic field, between either flat or pointed poles. In all cases, the optic axis, if horizontal, passed into the equatorial position; or, if vertical, left the cubes indifferent as to direction. It was easy by the method of two positions (2470.) to find the line of force, which, being vertical, left the mass unaffected by the magnet; or, being horizontal, went into the equatorial position; and then examining the cube by polarized light, it was found that this line coincided with the optic axis.

2598. Even the horse-shoe magnet (2485.) is sufficiently strong to produce these effects.

2599. I tried two similar cubes of rock-crystal (1692.), but could perceive no traces of any phenomena having either magneoptic, or magnecrystallic, or any other relation to the crystalline structure of the masses.

2600. But though it is thus very certain that there is a line in a crystal of calcareous spar coinciding with the optic axis, which line seems to represent the resultant of the forces which make the crystal take up a given position in the magnetic field; and, though it is equally certain that this line takes up its position in the equatorial direction; yet, considered as a line of force, *i. e.* as representing the direction of the force which places the crystal in that position, it seems to me to have something anomalous in its character. For, that a directing and determining *line* of force should have, as its full effect, the result of going into a *plane* (the equatorial), in which it can take up any one of an infinite number of positions indifferently, leaves an imperfect idea on my mind; and a thought, that there is some other effect or residual phenomena to be recognized and accounted for.

2601. On further consideration, it appears that a simple combination of the magnecrystalline condition, as it exists in bismuth, will supply us with a perfect representation of the state of calcareous spar; for, by placing two equal pieces of bismuth with their magnecrystallic axes perpendicular to each other (2484.), we have a system of forces which seems to possess, as a resultant, a line setting in the equatorial direction. When that line is vertical the system is, as regards position, indifferent; but when horizontal, the system so stands, that the line is in the equatorial plane. Still, the real force is not in the equatorial direction, but axial; and the system is moved by what may be considered a *plane of axial force* (resulting from the union of the two axes at right angles to each other), rather than by a *line of equatorial force.*

2602. Doubtless, the rhomboid or cube (2597.) of calcareous spar is not a compound crystal, like the system of bismuth crystals just referred to (2601.); but its molecules may possess a compound disposition of their forces, and may have two or more axes of power, which at the same time that they cause the crystalline structure, may exert such force in relation to the magnet, as to give results in the same manner, and of the same kind, as those of the double crystal of bismuth (2601.). Indeed,

that there should be but one axis of crystalline force, either in the particle of Iceland spar, or in those of bismuth, does not seem to me to be any way consistent with the cleavage of the substances in three or more directions.

2603. The optic axis in a piece of calcareous spar, is simply the line in which, if a polarized, or ordinary ray of light moves, it is the least affected. It may be a line which, as a resultant of the molecular forces, is that of the least intensity; and, certainly, as regards ordinary and mechanical means of observing cohesion, a piece of calcareous spar is sensibly, and much harder on the faces and parts which are parallel to the optic axis, than on those perpendicular to it. An ordinary file or a piece of sandstone shows this. So that the plane equatorial to the optic axis, as it represents directions in which the force causing crystallization is greater in degree than in the direction of the optic axis, may also be that in which the resultant of its magnecrystallic force is exerted.

2604. I am bound to state, as in some degree in contrast with such considerations, that, with bismuth, antimony and arsenic, the cleavage is very facile perpendicular to the magnecrystallic axis (2475. 2510. 2532.). But we must remember that the cleavage (and therefore the cohesive) force is not the only thing to be considered, for in calcareous spar it does not coincide with either the axial or the equatorial direction of the substance in the magnetic field: we must endeavour to look beyond this to the polar (or axial) condition of the particles of the masses, for the full understanding and true relation of all these points.

2605. I am bound, also, to admit that, if we consider calcareous spar as giving the simple system of force, we may, by the jaxtaposition of two crystals with their optic axes at right angles to each other, produce a compound mass, which will truly represent the bismuth in the direction of the force; *i. e.* it will, in the magnetic field, point with apparently one line of force only, and that in the axial direction, whilst it may be really moved by a system of forces lying in the equatorial plane. I will not at present pretend to say that this is not the state of things; but I think, however, that the metals, bismuth, antimony and arsenic, present us with the simplest as they do the strongest cases of magnecrystallic force; and whether that be so or not I am still of opinion that the phenomena discovered by PLÜCKER and those of which I have given an account in these two papers, have one common origin and cause.

2606. I went through all the experiments and reasonings with PLÜCKER's crystals (as the carbonate of lime, tourmaline and red ferro-prussiate of potassa), in reference to the question of original or induced power (2576.), as before, and came to the same conclusion as in the former case (2584.).

2607. I could not find that crystals of red ferro-prussiate of potassa or tourmaline were affected by the earth's magnetism (2581.), or that they had the power of affecting each other (2582.). Neither could I find that PLÜCKER's effect with calcareous spar, or red ferro-prussiate of potassa, was either an attractive or repulsive effect, but one connected with position only (2550. 2560.). All which circumstances tend to

convince me that the force active in his experiments, and that in my results with bismuth, &c., is the same*.

2608. A small rhomboid of Iceland spar was raised to the highest temperature in the magnetic field which a spirit-lamp could give (2570.); it was at least equal to the full red heat of copper, but it pointed as well then as before. A short thick tourmaline was heated to the same degree, and it also pointed equally well. As it cooled, however, it became highly magnetic, and seemed to be entirely useless for experiments at low temperatures; but on digesting it for a few seconds in nitromuriatic acid, a little iron was dissolved from the surface, after which it pointed as well, and in accordance with PLÜCKER's law, as before. A little peroxide upon the surface had been reduced by the flame and heat to protoxide, and caused the magnetic appearances.

2609. There is a general and, as it appears to me, important relation between PLÜCKER's magneto-optical results and those I formerly obtained with heavy glass and other bodies (2152, &c.). When any of these bodies are subject to strong induction under the influence of the magnetic or electric forces, they acquire a peculiar state, in which they can influence a polarized ray of light. The effect is a rotation of the ray, if it be passed through the substance parallel to the lines of magnetic force, or in other words, in the axial direction; but if it be passed in the equatorial direction, no effect is produced. The equatorial plane, therefore, is that plane in which the condition of the molecular forces is the least disturbed as respects their influence on light. So also in PLÜCKER's results, the optic axis, or the optic axes, if there be two, go into that plane under the same magnetic influence, they also being the lines in which there is the least, or no action on polarized light.

2610. If a piece of heavy glass, or a portion of water, could be brought beforehand into this constrained condition, and then placed in the magnetic field, I think there can be no doubt that it would move, if allowed to do so, and place itself naturally, so that the plane of no action on light should be equatorial, just as PLÜCKER shows that a crystal of calcareous spar or tourmaline does in his experiments. And, as in his case, the magnetic or diamagnetic character of the bodies, makes no difference in the general result; so in my experiments, the optical effect is produced in the same direction, and subject to the same laws, with both classes of substances (2185. 2187.).

2611. But though thus generally alike in this great and leading point, there is still a vast difference in the disposition of the forces in the heavy glass and the crystal;

* The optic axis is the direction of least optic force; and by PLÜCKER's experiments, coincides with what I consider in my results as the direction of minimum magnecrystallic force. It is more than probable that, wherever the two sets of effects (whether really or only nominally different) can be recognized in the same body, the directions of maximum effect, and also those of minimum effect, will be found to coincide.—November 23, 1848.

and there is a still greater difference in this, that the heavy glass takes up its state only for a time by constraint and under induction, whilst the crystal possesses it freely, naturally and permanently. In both cases, however, whether natural or induced, it is a state of the particles; and comparing the effect on light of the glass under constraint with that of the crystal at liberty, it indicates a power in the magnet of inducing something like that condition in the particles of matter which is necessary for crystallization; and that even in the particles of fluids (2184.).

2612. If there be any weight in these considerations, and if the forces manifested in the crystals of bismuth and Iceland spar be the same (2607.), then there is further reason for believing that, in the case of bismuth and the other metals named, there is, when they are subjected to the power of the magnet, both an induced condition of force (2584.), and also a pre-existing force (2577.). The latter may be distinguished as the crystalline force, and is shown, first, by such bodies exhibiting optic axes and lines of force when not under induction; by the symmetric condition of the whole mass, produced under circumstances of ordinary occurrence; and by the fixity of the line of magnecrystallic force in the bodies shown experimentally to possess it.

2613. Though I have spoken of the magnecrystallic axis as a given line or direction, yet I would not wish to be understood as supposing that the force decreases, or state changes, in an equal ratio all round from it. It is more probable that the variation is different in degree in different directions, dependent on the powers which give difference of form to the crystals. The knowledge of the disposition of the force can be ascertained minutely hereafter, by the use of good crystals, an unchangeable ordinary magnet (2485. 2528.), or a regulated electro-magnet, flat-faced poles (2463.), and torsion (2500. 2530.).

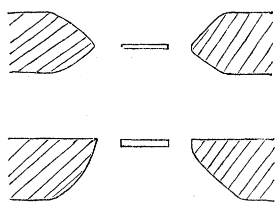
2614. I cannot conclude this series of researches without remarking how rapidly the knowledge of molecular forces grows upon us, and how strikingly every investigation tends to develope more and more their importance, and their extreme attraction as an object of study. A few years ago magnetism was to us an occult power, affecting only a few bodies; now it is found to influence all bodies, and to possess the most intimate relations with electricity, heat, chemical action, light, crystallization, and, through it, with the forces concerned in cohesion; and we may, in the present state of things, well feel urged to continue in our labours, encouraged by the hope of bringing it into a bond of union with gravity itself.

Royal Institution,
October 20, 1848.

¶ vi. Note.—*On the position of a crystal of sulphate of iron in the magnetic field.*

Received December 7, 1848.—Read December 7, 1848.

Fig. 6.



2615. Though effects of the following nature are general, yet I think it convenient to state that I obtained them chiefly by the use of magnetic poles (2247.), the form of which is given in the plan and side view annexed (fig. 6.). The crystals submitted to their action were suspended by cocoon silk, so as to be level with the upper surface of the poles.

2616. A prismatic crystal of proto-sulphate of iron was selected, which was nearly 0·9 of an inch in length, 0·1 in breadth, and 0·05 in thickness; by examination the magnecrystallic axis was found to coincide with the thickness, and therefore to be perpendicular, or nearly so (2546.), to the plate. Being suspended as above described, and the magnet (2247.) excited by ten pair of Grove's plates, the crystal stood transverse, or with its *magnecrystallic axis* parallel to the axis of magnetic force, when the distance between the poles was 2·25 inches or more; but when the distance was about two inches or less, then it stood with its length axial, or nearly so, and its magnecrystallic axis therefore transverse to the lines of magnetic force. In the intermediate distances between 2 and 2·25 inches, the prism assumed an oblique position (2634.), more or less inclined to the axial line, and so passing gradually from the one position to the other. This intermediate distance I will for the present call *n* (neutral) distance.

2617. If the poles be two inches apart and the crystal be gradually lowered, it passes through the same intermediate oblique positions into the transverse position; or if the crystal be raised, the same transitions occur; at any less distance the changes are the same, but later. They occur more rapidly when the crystal is raised than when it is lowered; but this is only because of the unsymmetric disposition and intensity of the lines of magnetic force around the magnetic axis, due to the horse-shoe form of the magnet and shape of the poles. If two cylinder magnets with equal conical terminations were employed, there is no doubt that for equal amounts of elevation or depression, corresponding changes would take place in the position of the crystal.

2618. These changes however are not due to mere diminution of the magnetic force by distance, but to differences in the *forms* or *direction* of the resultants of force. This is shown by the fact that, if the crystal be left in its first position, and so pointing with the length axially, no diminution of the force of the magnet alters the position; thus, whether one or ten pair of plates be used to excite the magnet, the *n* distance (2616.) remains unchanged; and even descending to the use of an ordinary horse-shoe magnet, I have found the same result.

2619. Variation in the length of the prismatic crystal has an important influence

over the result. As the crystal is shorter the distance *n* diminishes, all the other phenomena remaining the same. A crystal 0·7 of an inch long, but thicker than the last, had for its maximum *n* distance 1·7 inch. A still shorter crystal had for its maximum *n* distance 1·1 inch. In all these cases variation of the force of the magnet caused no sensible change.

2620. Variation in that dimension of the crystal coincident with the magnecrystallic axis affected the *n* distance: thus, increase in the length of the magnecrystallic axis diminished the distance, and diminution of it in that direction increased the distance. This was shown in two ways; first, by placing a second prismatic crystal by the side of the former in a symmetric position (2636.), which reduced the *n* distance to between 1·75 and 2 inches; and next, by employing two crystals in succession of the same length but different thicknesses. The thicker one had the smaller *n* distance.

2621. Variation in the depth of the crystal, *i. e.* its vertical dimension, did not produce any sensible effect on the *n* distance: nor by theory should it do so, until the extension upwards or downwards brings the upper or lower parts into the condition of raised or depressed portions (2617.).

2622. Variation in the form of the poles affects the *n* distance. As they are more acute, the distance increases; and as they are more obtuse up to flat-faced poles (2463.), the distance diminishes.

2623. With the shorter crystals, or with obtuse poles, it is often necessary to diminish the power of the magnet, or else the crystal is liable to be drawn to the one or other pole. This, however, may be avoided by employing a vertical axis which is confined below as well as above (2554.); and then the difference in *strength* of the magnet is shown to be indifferent to the results, or very nearly so.

2624. These effects may probably be due to the essential difference which exists between the ordinary magnetic and the magnecrystallic action, in that the first is *polar*, and the second only *axial* (2472.) in character. If a piece of magnetic matter, iron for instance, be in the magnetic field, it immediately becomes polar (*i. e.* has terminations of different qualities). If many iron particles be there, they all become polar; and if they be free to move, arrange themselves in the direction of the axial line, being joined to each other by contrary poles; and by that the polarity of the extreme particles is increased. Now this does not appear to be at all the case with particles under the influence of the magnecrystallic force; the force seems to be altogether *axial*, and hence probably the difference above, and in many other results.

2625. Thus, if four or more little cubes of iron be suspended in a magnetic field of equal force (2465.), they will become polar; if also four similar cubes of crystallized bismuth be similarly circumstanced, they will be affected and point. If the iron cubes be arranged together in the direction of the equatorial line, they will form

an aggregate in a position of unstable equilibrium, and will immediately, as a whole, turn and point with the length axially; whereas the bismuth cubes by such approximation will suffer no sensible change.

2626. The *extreme* (and the other) associated cubes of the elongated iron arrangement now have a polar force above that which they had before; and the whole group serves, as it were, as a conductor for the lines of magnetic power; for many of them concentrate upon the iron, and the intensity of power is much stronger between the ends of the iron arrangement and the magnetic poles, than it is in other parts of the magnetic field. Such is not the case with the bismuth cubes; for however they be arranged, the intensity of force in the magnetic field is, as far as experiments have yet gone, unaffected by them; and the intensity of the molecules of the crystals appears to remain the same. Hence the iron stands lengthways between the poles; the bismuth crystals, on the contrary, whether arranged side by side, as respects the magnecrystallic axis, so as to stand as to length equatorially; or end to end, so as to stand axially, are perfectly indifferent in that respect, vibrating and setting equally both ways.

2627. A given piece of iron when introduced into a field of equal magnetic force, and brought towards the pole, adheres to it and disturbs the intensity of the field, producing a pointed form of pole in one part with diverging lines of force: a crystal of bismuth vibrates with sensibly equal force in every part of the field (2467.), and does not disturb the distribution of the power.

2628. Considering all these actions and conditions, it appears to me that the occurrence of the *n* distance with a body which is at the same time magnetic and magnecrystallic, may be traced to that which causes them and their differences, namely, the *polarity* belonging to the magnetic condition, and the *axiality* belonging to the magnecrystallic condition. Thus, suppose an uniform magnetic field three inches from pole to pole, and a bar of magnetic matter an inch long, suspended in the middle of it; by virtue of the polarity it acquires, it will point axially, and carry on, or conduct, with its mass, the magnetic force, so much better than it was conducted in the same space before, that the lines of force between the ends of this bar and the magnetic poles, will be concentrated and made more intense than anywhere else in the magnetic field. If the poles be made to approach towards the bar, this effect will increase, and the bar will conduct more and more of the magnetic force, and point with proportionate intensity. It is not merely that the magnetic field becomes more intense by the approximation of the poles, but the proportion of force carried on by the bar becomes greater as compared to that conveyed onwards by an equal space in the magnetic field at its side.

2629. But if a similar bar of magnecrystallic substance be placed in the magnetic field, its power does not rise in the same manner, or in the same great proportion, by approximation of the poles. There can be no doubt that such approximation increases the intensity of the lines of force, and therefore increases the intensity of

the magneto-crystallic state; but this state does not appear to be due to polarity, and the bar does not convey more power through it than is conveyed onwards elsewhere through an equal space in the magnetic field. Hence its directive force does not increase in the same rapid degree as the directive force of the magnetic bar just referred to.

2630. If then we take a bar which, like a prism of sulphate of iron, is magnetic, and also magnecrystallic, having the magnecrystallic axis perpendicular to its length, such a bar, properly suspended, ought to have an *n* distance of the poles, within which the forces ought to be nearly in equilibrium; whilst at a greater distance of the poles, the magnecrystallic force ought to predominate; and at a lesser distance, the magnetic force ought to have the advantage; simply, because the magnetic force, in consequence of the true polarity of the molecules, grows up more rapidly and diminishes more rapidly than the magneto-crystallic force.

2631. This view, also, is consistent with the fact that variation of the force of the magnet does not affect the *n* distance (2618. 2619.); for, whether the force be doubled or quadrupled, both the magnetic and magneto-crystallic forces are at the same time doubled or quadrupled; and their proportion therefore remains the same.

2632. The raising or lowering of the crystal above or below the line of maximum magnetic force is manifestly equivalent in principle to the separation of the magnetic poles; and therefore should produce corresponding effects: and that is the case (2617.). Besides that, when the crystal is raised above the level of the poles, such resultants of magnetic force as pass through it, are no longer parallel to its length, but more or less curved, so that they probably cannot act with the same amount of power in throwing the whole crystal into a consistent polarized magnetic condition, as if they were parallel to it: whereas, as respects the induction of the magneto-crystallic condition, each of the particles appears to be affected independently of the others; and, therefore, any loss of an effect dependent upon joint action would not be felt here.

2633. M. Plücker told me, when in England in August last, that the repulsive force on the optic axis diminishes and increases less rapidly than the magnetic force, by change of distance; but is not altered in its proportion to the magnetic force by employing a stronger or weaker magnet. This is manifestly the same effect as that I have been describing; and makes me still more thoroughly persuaded that his results and mine are due to one and the same cause (2605. 2607.).

2634. I have said that, within the *n* distance, the crystal of sulphate of iron pointed more or less obliquely (2616.); I will now state more particularly what the circumstances are. If the distance *n* be so adjusted, that the prismatic crystal, which is at the time between the magnetic poles, shall make an angle of 30° (or any quantity) with the axial line; then it will be found that there is another stable position, namely, the diametral position (2461.), in which it can stand; but that the obliquity

is always on the same side of the axial line; and that the crystal will not stand with the like obliquity of 30° on the opposite side of the magnetic axis.

2635. If the crystal be turned 180° round a vertical axis, or end for end, then the inclination, and the direction in which it occurs, remain unchanged; in fact, it is simply giving the crystal the diametral position. But if the crystal be revolved 180° round a horizontal axis; either that coinciding with its length, which represents its maximum magnetic direction; or that corresponding with its breadth, and therefore with the magnecrystallic axis; then the inclination is the same in amount as before, but it is on the *other* side of the axial line.

2636. This is the case with all the prismatic crystals of sulphate of iron which I have tried. The effect is very determinate; and, as would be expected, when two crystals correspond in the direction of the inclination, they also correspond in the position of their form and direction of the various planes.

2637. All these variations of position indicate an oblique resultant of setting force, derived from the joint action of the magnetic and magnecrystallic forces; and would be explained by the supposition, that the magnecrystallic axis or line of maximum magnecrystallic force, was not perpendicular to the chief planes of the crystal (or those terminating it), but a little inclined in the direction of the length.

2638. Whether this be the case, or whether the maximum line of magnetic force may not, even, be a little inclined to the length of the prism; still, the n distance supplies an excellent experimental opportunity of examining this inclination, however small its quantity may be; because of the facility with which the influence of either the one or the other may be made predominant in any required degree.

Royal Institution,
December 5, 1848.

2639. *Note.* (2591.) Another supposition may be thrown out for consideration. I have already said that the assumption of a mere axial condition (2587. 2591.) would account for the set without attraction or repulsion. Now if we suppose it possible that the molecules should become polar in relation to the north and south poles of the magnet, but with *no mutual relation amongst themselves,* then the bismuth or other crystal might set as if induced with mere axial power: but it seems to me very improbable that polarities of a given particle in a crystal should be subject to the influence of the polarities of the distant magnet poles, and not also to the *like polarities* of the contiguous particles.—January 24, 1849.